Diffraction @ STAR and Roman Pots

A. Bravar, BNL; S.R. Klein, LBNL; *et al.*

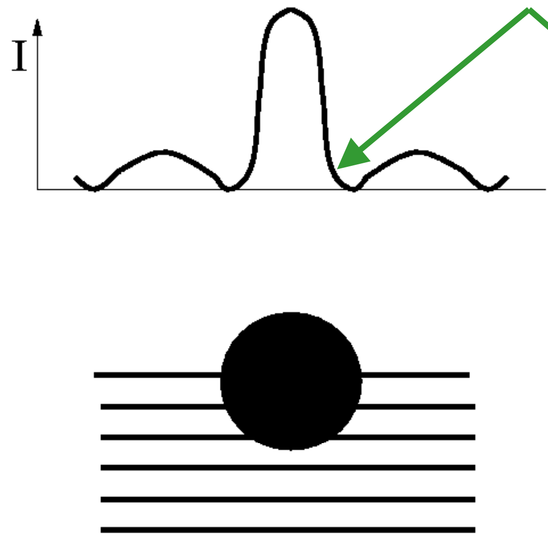
- what is diffraction ?
- central production (a central mystery !?)
- hard diffraction
- Roman Pot setup & trigger
- conclusions

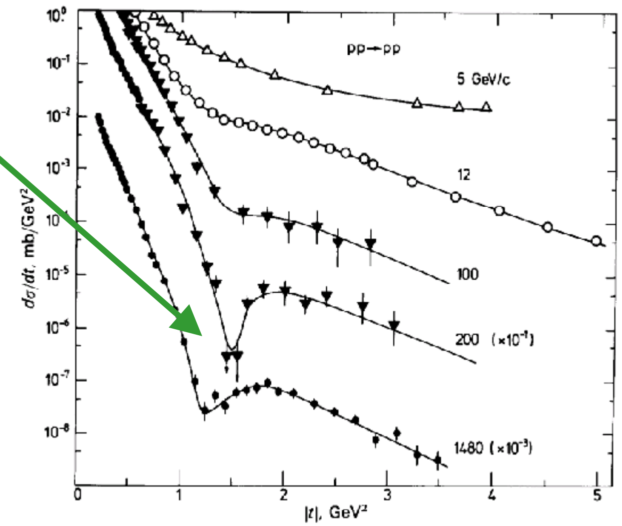
STAR upgrade
Bar Harbor Jun 18, 2002

BROOKHAVEN NATIONAL LABORATORY

What is Diffraction ? 1

diffractive dip



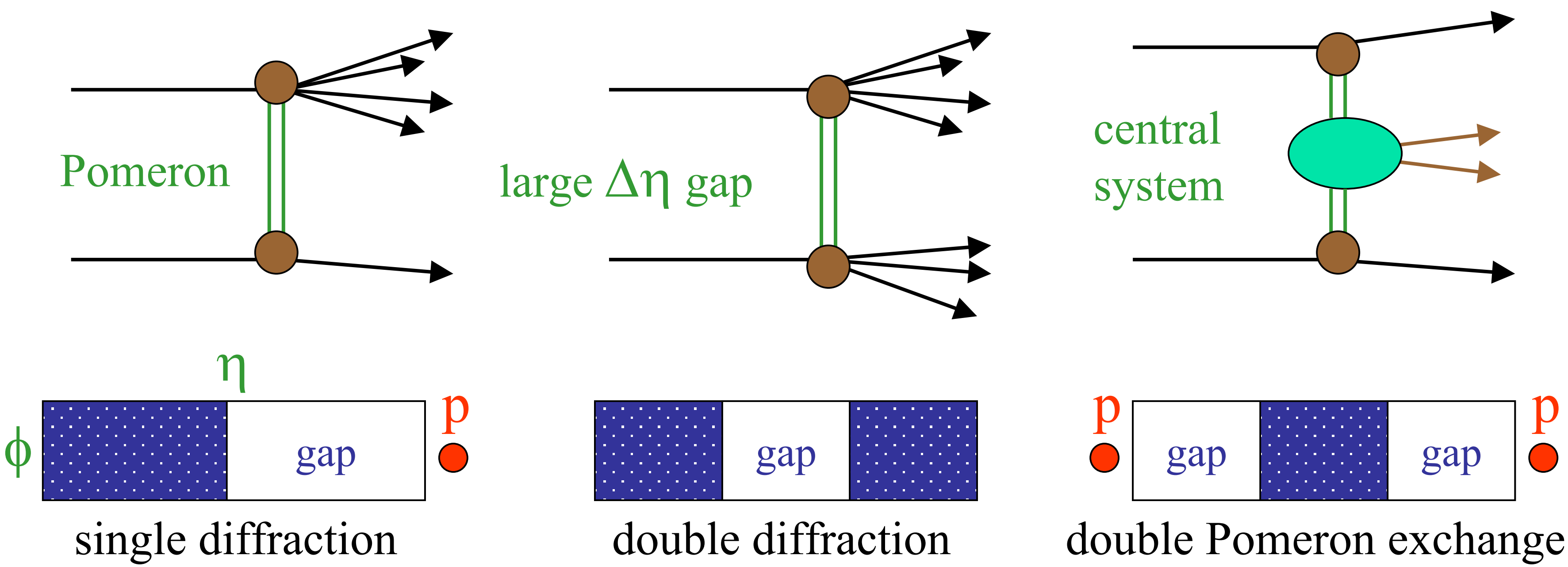


optics → hadron elastic scattering

diffraction: shadow of inelastic interactions

> 20% of σ_{tot} → huge rates

What is Diffraction?



- Diffraction = Rapidity Gap

  presumed to be caused by Pomeron exchange

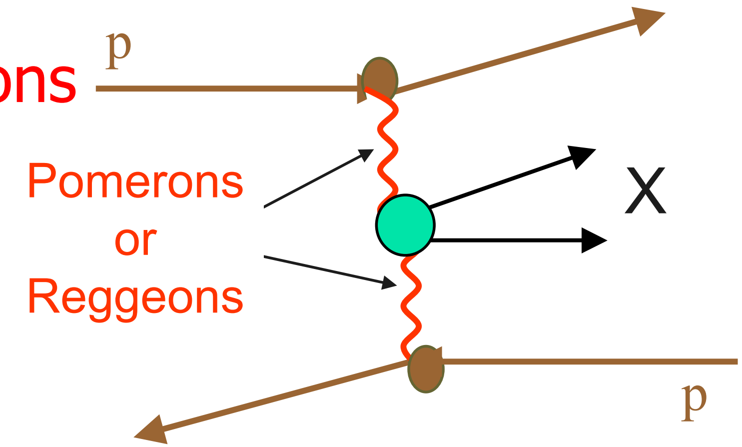
- Pomeron: color-singlet combination of gluons and/or quarks

  with quantum number of the vacuum 0^+ ? (folklore)

  central production $\rightarrow$ 1^-: non conserved vector current !?

Diffraction in *pp* – 2 $\mathbb{P}$ Exchange

Can exchange both Reggeons & Pomerons



$\sigma(\mathbb{P}\mathbb{P}) \sim s^{0.08 - 0.16}$

$\sigma(\mathbb{P}\mathbb{R}) \sim s^{-0.5}$

$\sigma(\mathbb{R}\mathbb{R}) \sim s^{-1}$

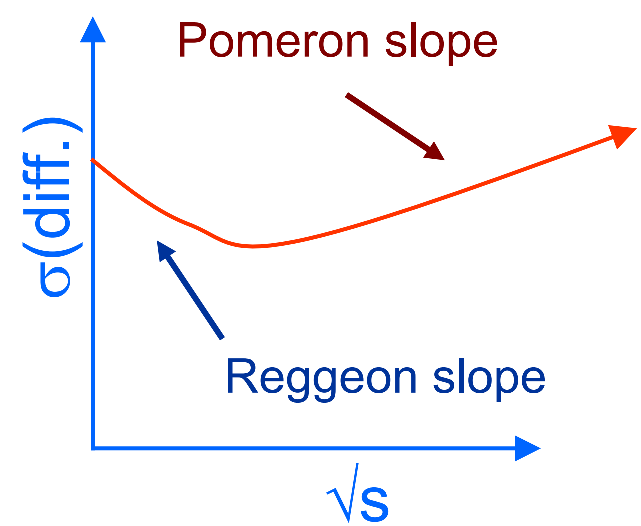
- as $\sqrt{s}$ grows, $\mathbb{R}$ exchange less important,

  might interfere with $\mathbb{P}$ exchange (phase !)

  $\rightarrow$ amplification of $\mathbb{R}$ exchange
- no baryon resonance contamination
- $\sigma(\mathbb{P}\mathbb{P}) \sim 200\ \mu b$

  0.4% of $\sigma_{tot} \rightarrow$ high rates
- $d\sigma/dM \sim 1/M^3$

  concentrated at lower masses



HADRONS - *color singlets*

conventional

baryons: $|qqq\rangle$, $|\bar{q}\bar{q}\bar{q}\rangle$

mesons: $|q\bar{q}\rangle$

exotica

multiquarks (clusters and molecules) : $|qq\bar{q}\bar{q}\rangle$, $|qqqqqq\rangle$, ...

controversial, may not exist as resonances

fall-apart decays allow direct coupling of $|q\bar{q}\rangle$ & $|q\bar{q}\rangle$ without interactions

glueballs (*excited glue*): $|gg\rangle$, $|ggg\rangle$, ...

maybe 1 known ($f_0(1500)$)

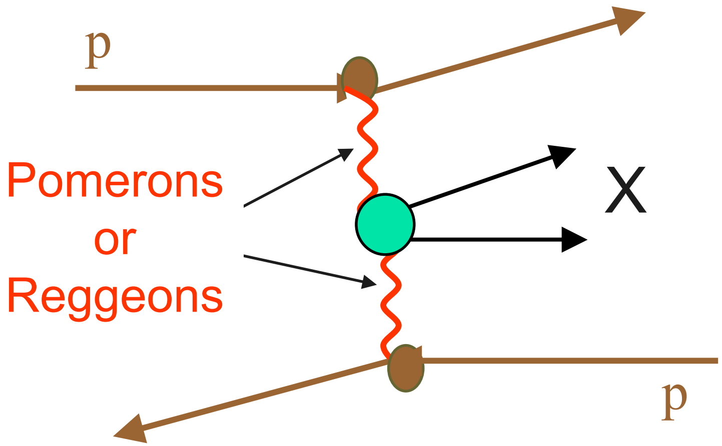
lattice QCD

hybrids (quarks + *excited glue*): $|q\bar{q}g\rangle$, $|qqqg\rangle$, ...

maybe 2 – 3 known ($\pi_1(1600)$)

exotic quantum numbers (i.e. forbidden to qq: 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}…)

Central Production



Central *low mass* system < 4 – 5 GeV

$pp \to p\,(\pi^+\pi^-)\,p$ (simplest !)

$pp \to p\,(K^+K^-)\,p$

$pp \to p\,(\pi^+ K^0{}_s K^-)\,p$ (exotic 1^{-+})

……

RICH structure (several resonances …)

⇒ ideal for hadron spectroscopy

at lower p_T rich in gluons

⇒ glueball searches

Protons go down beam pipe → detect (trigger & tag) with roman pots

detection of scattered proton(s) will fix the event kinematics:

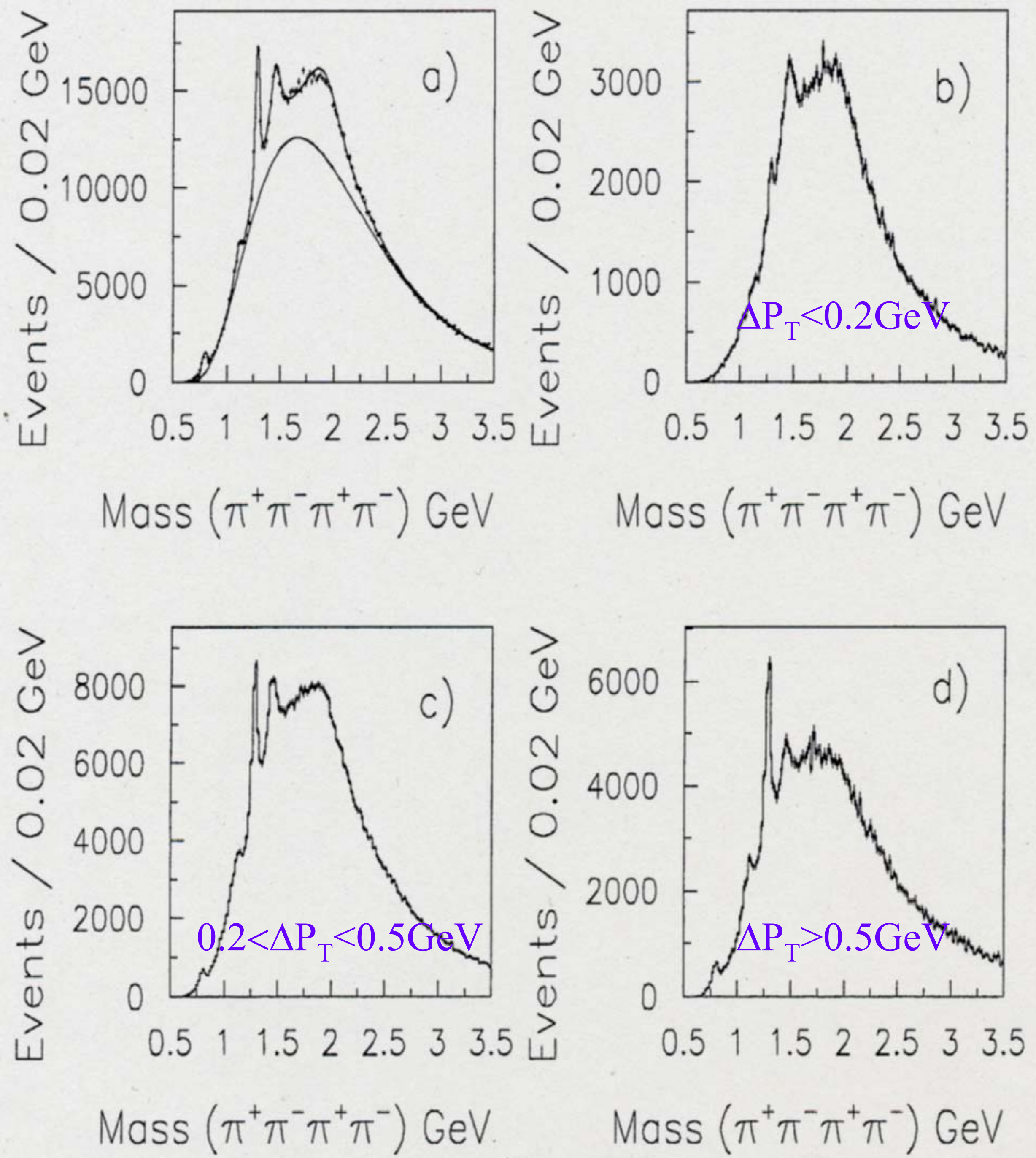
momentum transfer ***t***, azimuth, energy loss

interesting ***t***: $0.05 < |t| < 1\ \mathrm{GeV}^2$ $(0.25 < p_T < 1\ \mathrm{GeV})$

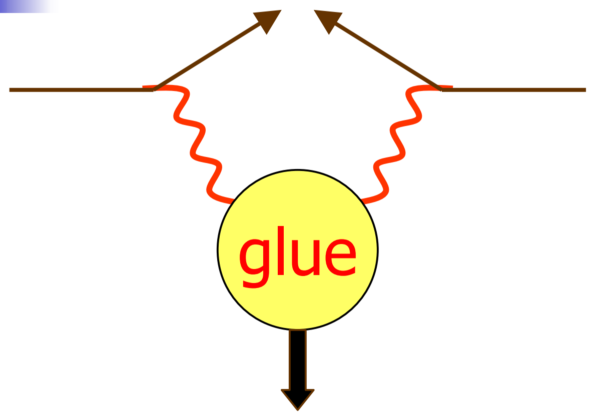
An Example of 4 Prong $(\pi^+\pi^- \pi^+\pi^-)$ Events

WA102 @ CERN

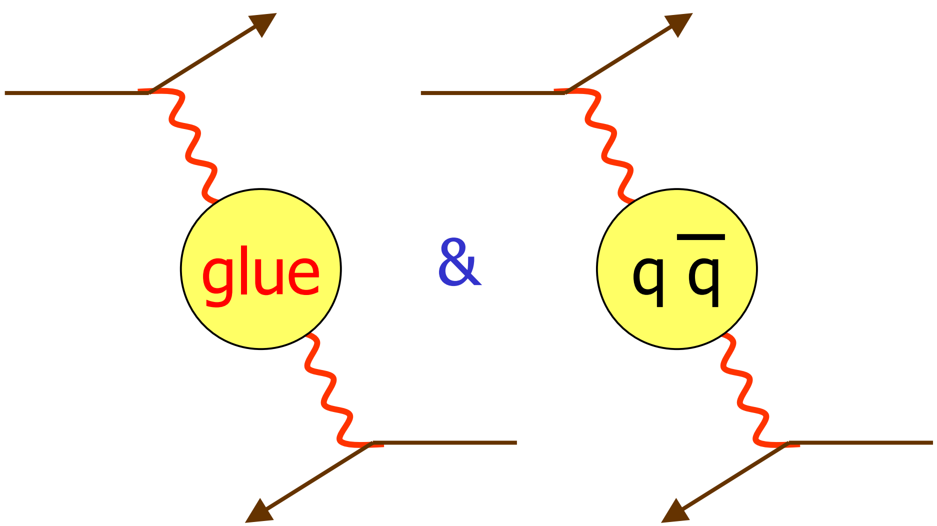
both scattered protons are measured !



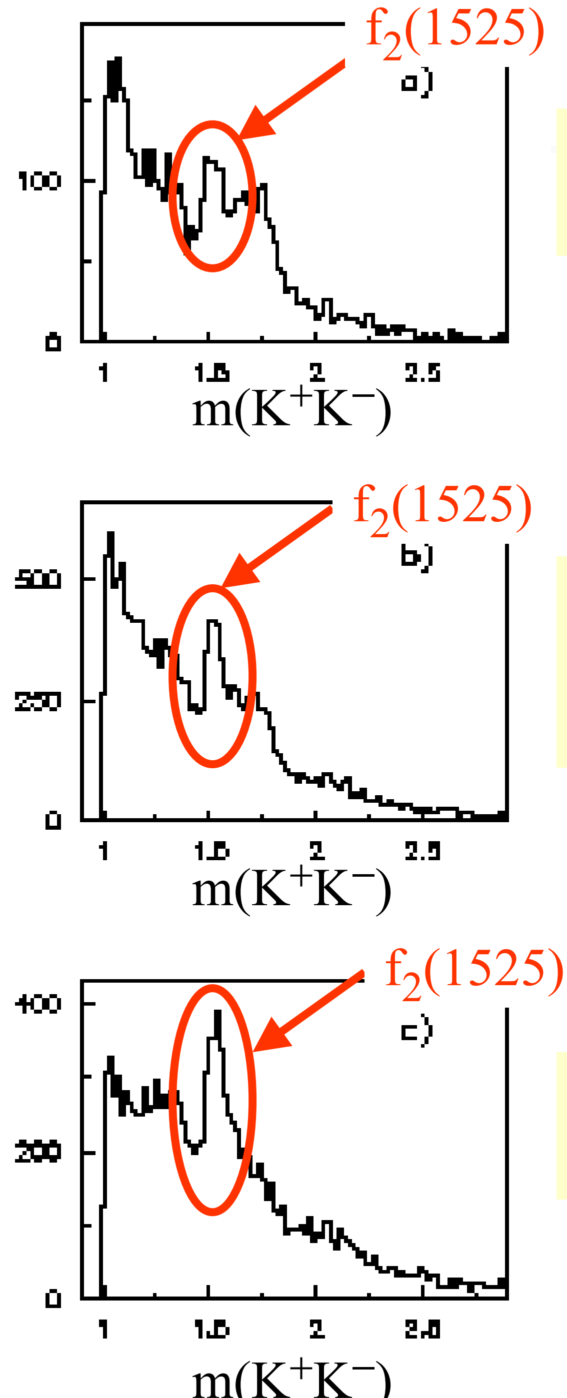
Δp_T Filter



gentle: $\Delta p_T = |p_{T1} - p_{T2}|$ small



violent: $\Delta p_T = |p_{T1} - p_{T2}|$ large

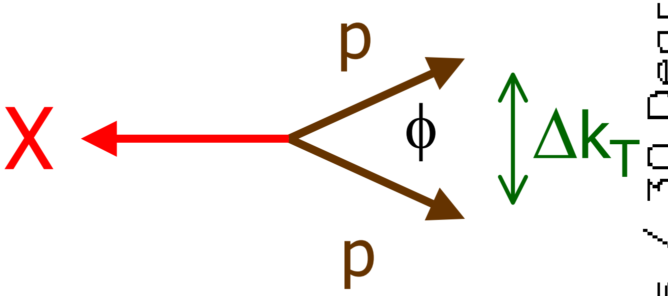


$\Delta P_T <$ 0.2 GeV

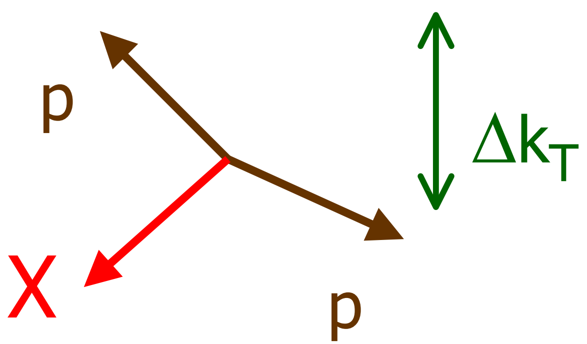
0.2 GeV $< \Delta P_T <$ 0.5 GeV

$\Delta P_T >$ 0.5 GeV

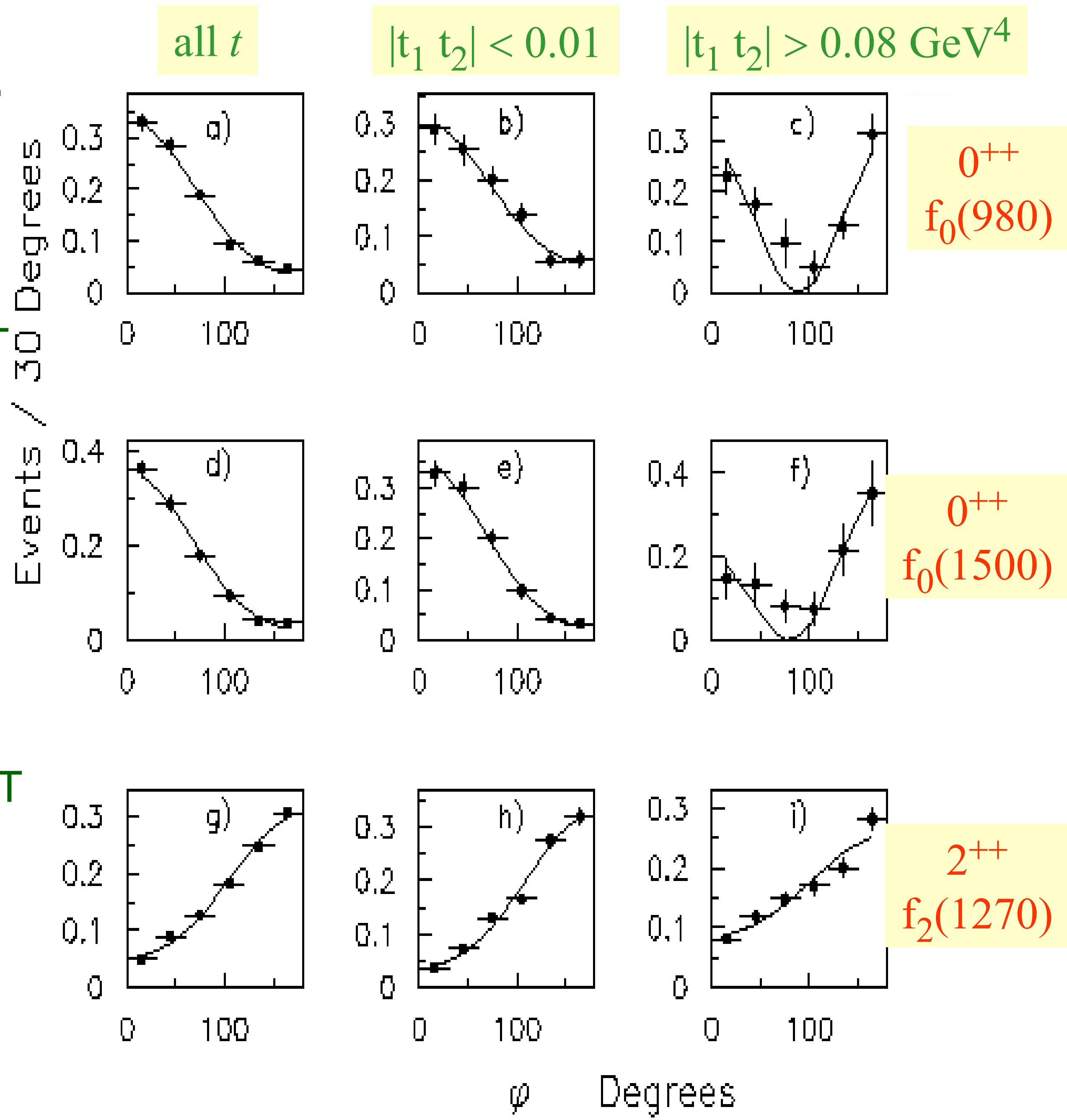
$\Delta p_T \rightarrow \phi$



Δk_T small $\rightarrow$ gentle



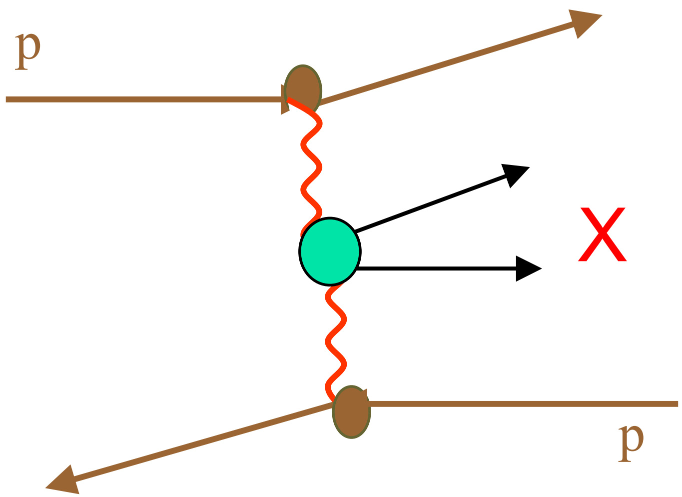
Δk_T large $\rightarrow$ violent



A Central Mystery

QCD allows exotic states →

RHIC with polarized protons can search through central production



What is X ?

G vs $q\bar{q}$ (mixing)

How Pomeron works ?

scalar 0^+ vs

non-conserved vector current 1^-

- The p_T filter and azimuthal dependences observed at the SPS remain compelling and unexplained: 0^+ vs 1^- Pomeron
- Suggestive of *spin effects*: *spin effects* seem likely
- It is likely that studies with polarized protons will shed new light on this phenomenon and might help to disentangle the different resonances

Specific Cross Sections & Rates

$\mathscr{L} = 10^{31}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

Assuming $\int \mathscr{L}\, dt \sim 1.2 \times 10^{36}\ \mathrm{cm}^{-2}$ i.e. 50% duty cycle, 10% efficiency, 1 month run

		Final State	σ(μb)	# Evts.
		pp ($\pi^+\pi^-$)	79 ± 13	95 M
$\sqrt{S} \sim 60$	ISR	pp ($2\pi^+2\pi^-$)	46 ±10	55 M
		pp (K^+K^-)	6.5 ± 1.7	7.8 M
		pp ($K^+K^-\pi^+\pi^-$)	10.0 ± 3.3	12 M
$\sqrt{S} \sim 30$	WA102	pp $f_0(980)$	5.7 ± 0.5	6.8 M
		pp $f_0(1500)$	2.9 ± 0.3	3.5 M
		pp $f_2(1270)$	3.3 ± 0.4	4.0 M
		pp $f_2(1950)$	2.8 ± 0.2	3.4 M

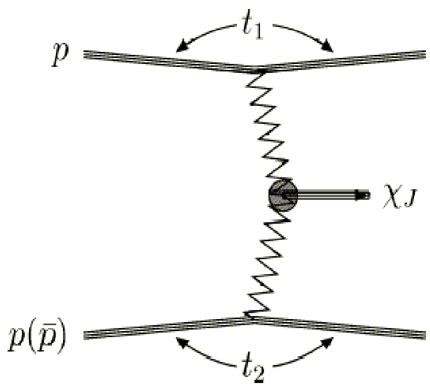
← 1/3 of σ (PP) ?

ππ decay dominant

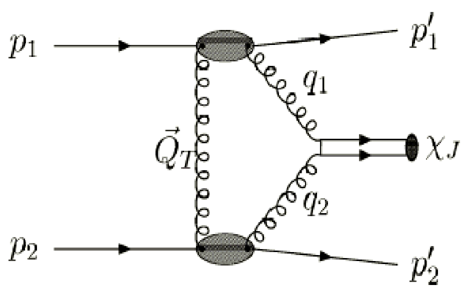
rates are huge: prescaling or very selective trigger

search for more rare and exotic states

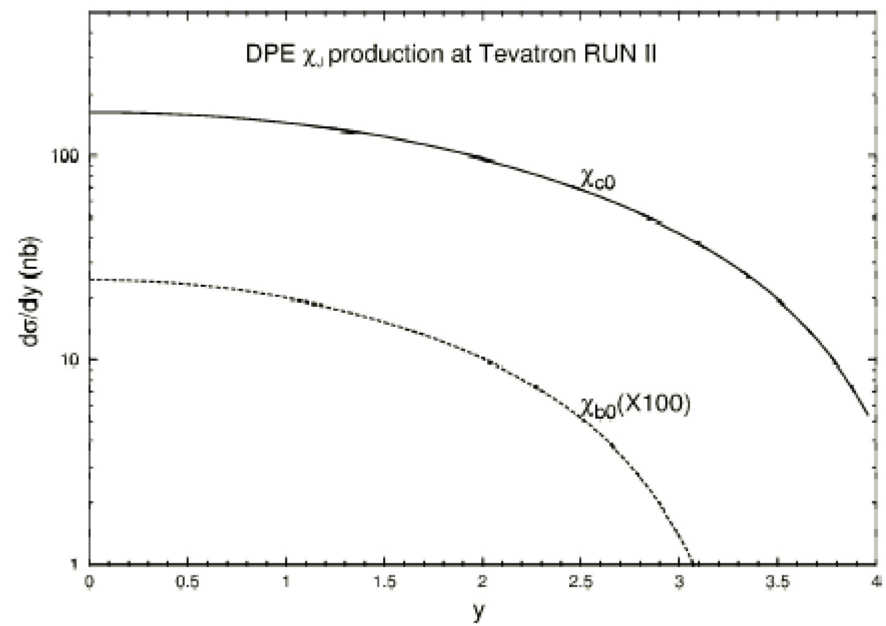
An intermediate case: charmonium χ_{c0}



(a)



(b)



$\sigma(\chi_{c0})$ = 735 nb @ Tevatron

guess ~ 73 nb for 500 GeV pp

$\rightarrow$ 730,000/10^6 s at L = 10^{32} /cm^2/s

good rates for $\gamma J/\Psi$, $\pi^+\pi^-\pi^+\pi^-$, etc.

Why Central Production with STAR ?

interesting physics & novel effects

extension of UPC to *pp*

higher energy than previous experiments

- $\rightarrow$ smaller meson exchange contribution (no baryon resonances)
- $\rightarrow$ better isolation (larger rapidity gaps)
- $\rightarrow$ higher mass states (charmonia)
- $\rightarrow$ more exotic final states

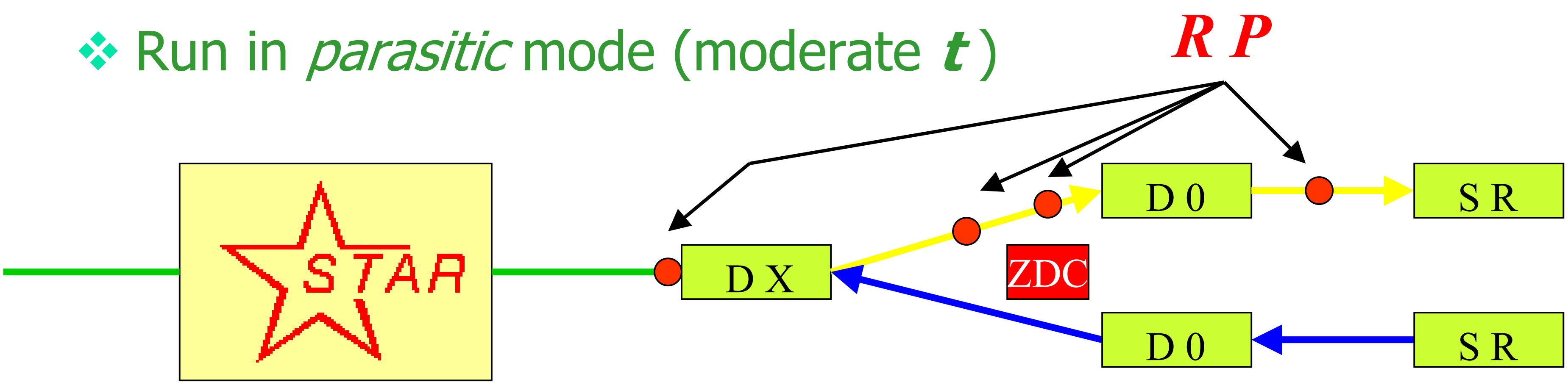
polarized beams

- $\rightarrow$ spin might help disentangle mixing of various resonances
- $\rightarrow$ spin might highlite G / $q\bar{q}$ dynamics

good acceptance for central production

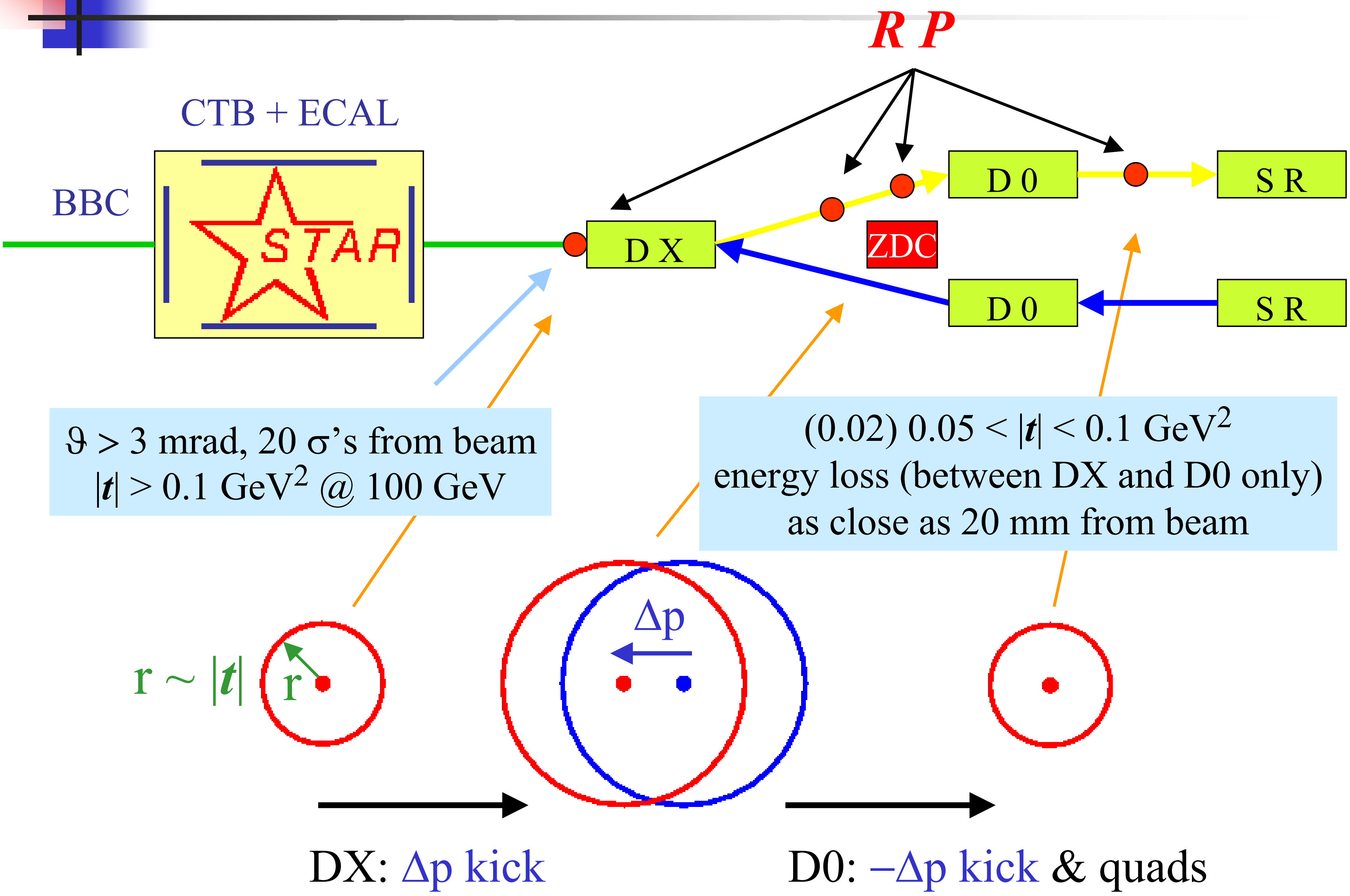
Roman Pot Setup with Star Detector

- Roman Pots ≡ Forward Proton Spectrometer
- Fully reconstruct the event kinematics & trigger on very forward protons
- Low impact on STAR detector
- Run in *parasitic* mode (moderate ***t***)



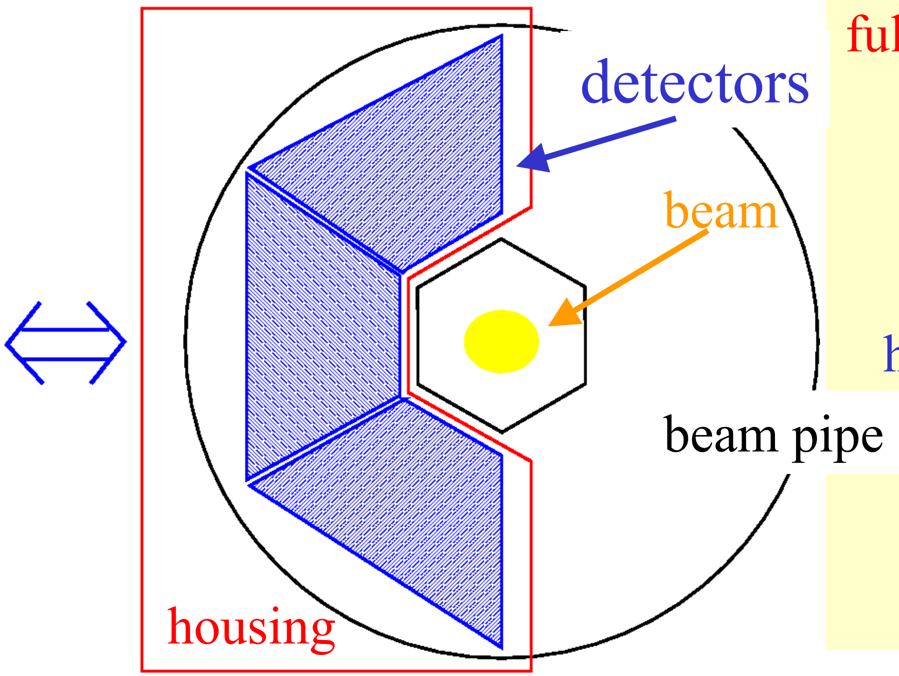
- can be used also as luminosity monitor
  multiplicity counter down to $\eta = -6.5$
  very forward veto

Roman Pots



R P
CTB + ECAL
BBC
STAR
D X
D 0
S R
ZDC
D 0
S R
ϑ > 3 mrad, 20 σ's from beam
|t| > 0.1 GeV² @ 100 GeV
(0.02) 0.05 < |t| < 0.1 GeV²
energy loss (between DX and D0 only)
as close as 20 mm from beam
r ~ |t|
r
Δp
DX: Δp kick
D0: –Δp kick & quads

Roman Pots 2

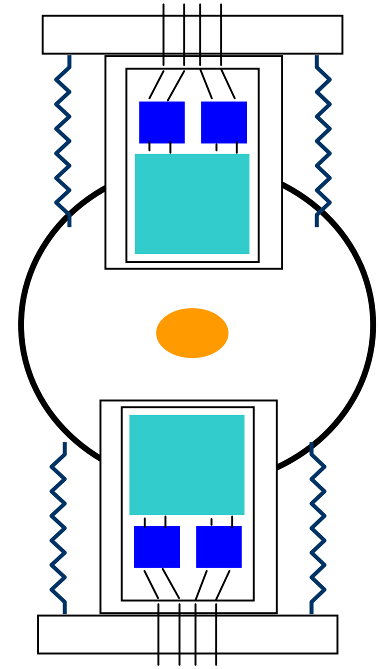


full coverage in azimuth

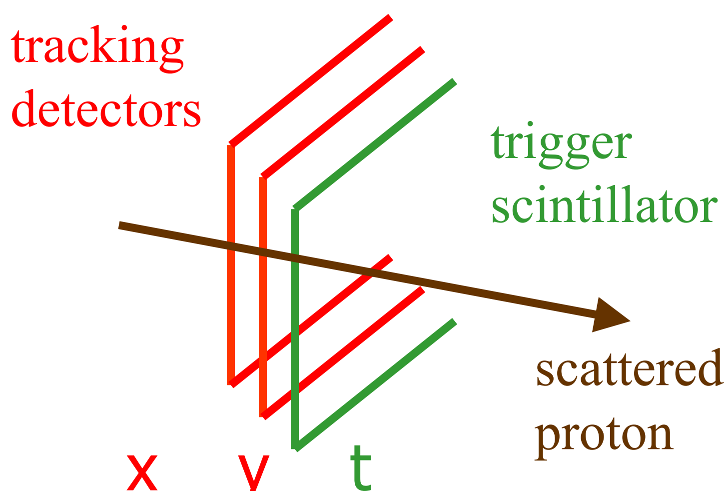
hexagonal shape
or rectangular

horizontal & vertical
segmentation
(or η & φ)

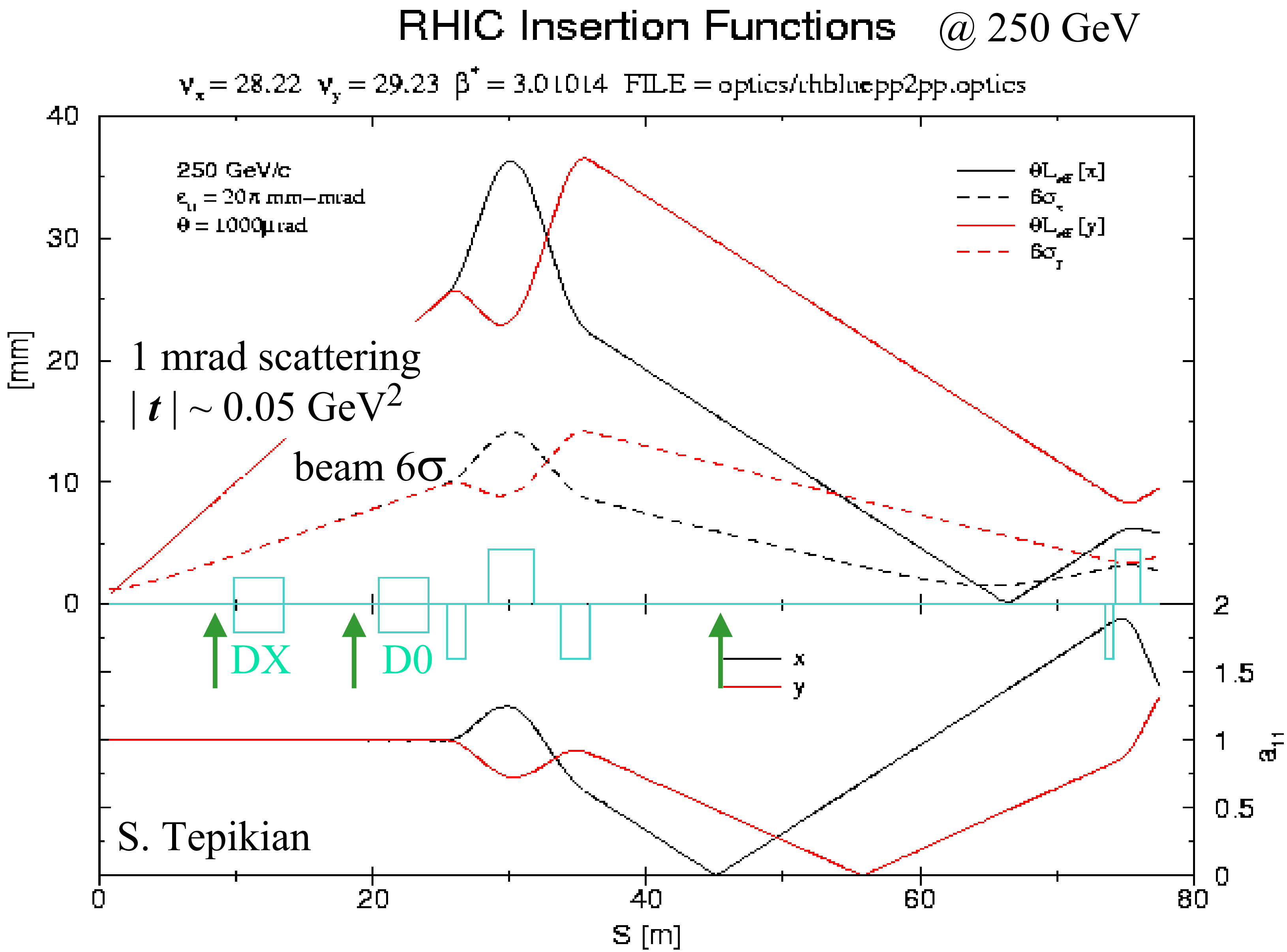
~ 200 μ resolution



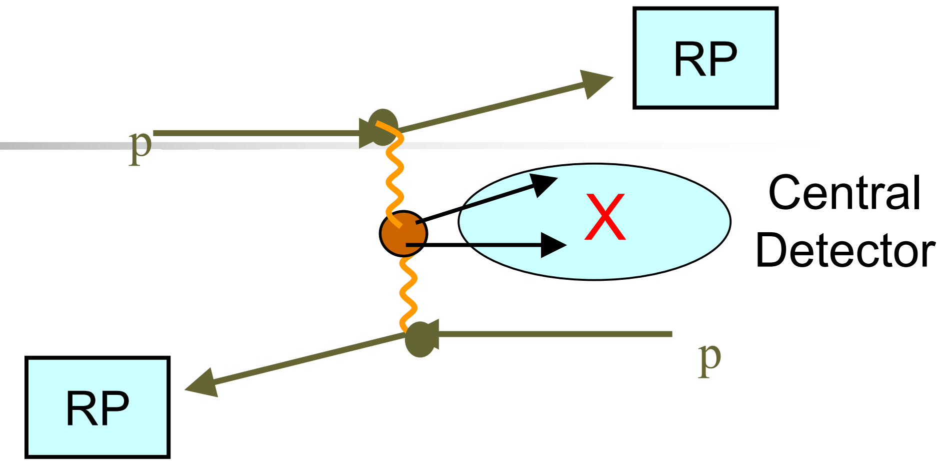
silicon or scintillating fibers
X & Y
~ 60 x 60 mm^2
~ 200 μ resolution



Beam Transport Calculations



Triggering



- Central production
  - Signals in both Roman Pots **AND** UPC trigger

    (UPC trigger + Roman Pots veto $\rightarrow$ very low ***t***)

- Hard Diffraction
  - Select final states with central detector

    high-p_T di-jets, high-p_T leptons, etc.
  - Supplement (tag) with roman pots

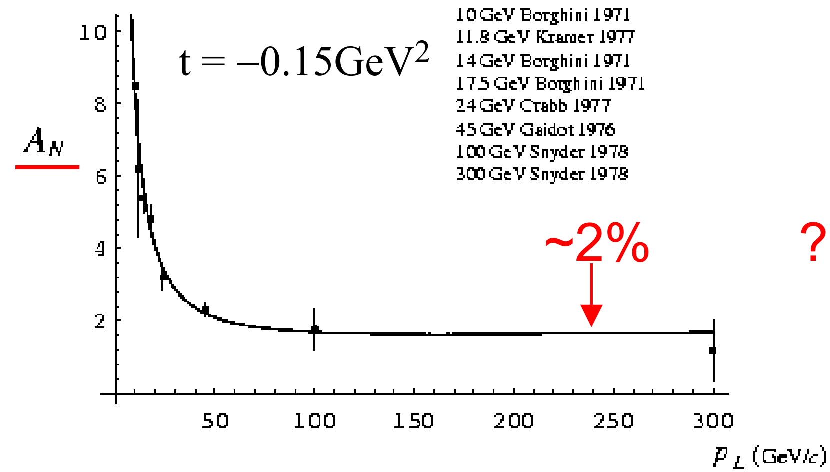
    both roman pots $\rightarrow$ DPE

    only one pot $\rightarrow$ Single Diffraction
  - Scale rates from central events $\rightarrow$ avoid trigger efficiency

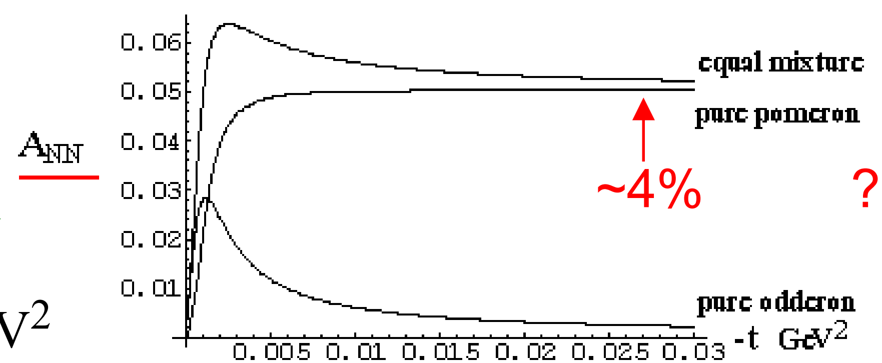
Elastic Scattering

L. Trueman *et al*. predictions

pp2pp detailed program for *pp* elastic scattering
including A_N, A_{NN} (spin)
however no longitudinal polarization
not too large ***t*** (i.e. $|t|$ > few GeV^2)



If spin asymmetries as large as expected
pp elastic scattering can be used as a
local polarimeter (transverse spin)
for all RHIC experiments



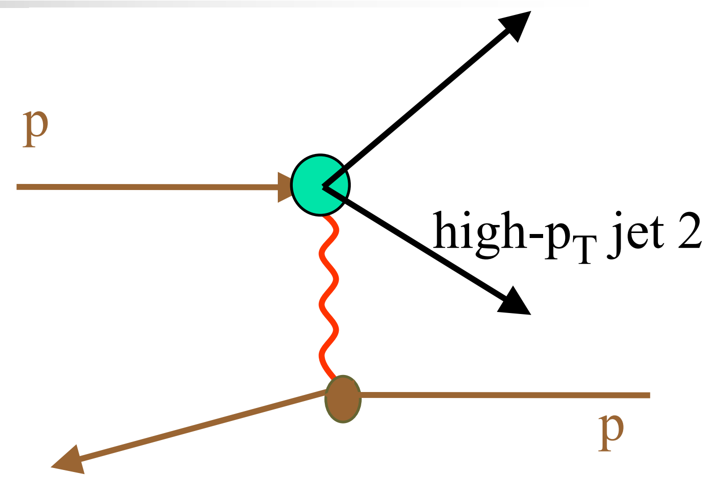
A_{LL}: not much known nor predicted
If $A_{LL} \sim A_{NN}$ access also to longitudinal spin

Roman Pots can work at $|t|$ as low as 0.05 GeV^2
under normal beam conditions, incl. $\beta^* \sim 1$ m

At $|t| = 0.15$ GeV^2, $\sigma_{pp} > 10^{-28}$ cm^2 $\Rightarrow$ > 10^6 events / day (clean and simple process !)
$\rightarrow$ $\Delta P / P \sim \Delta A / A < 10\%$ (systematics dominated, not statistics)
$\rightarrow$ very efficient polarimeter for free **!**

Hard Diffraction

discovered by UA8 @ CERN

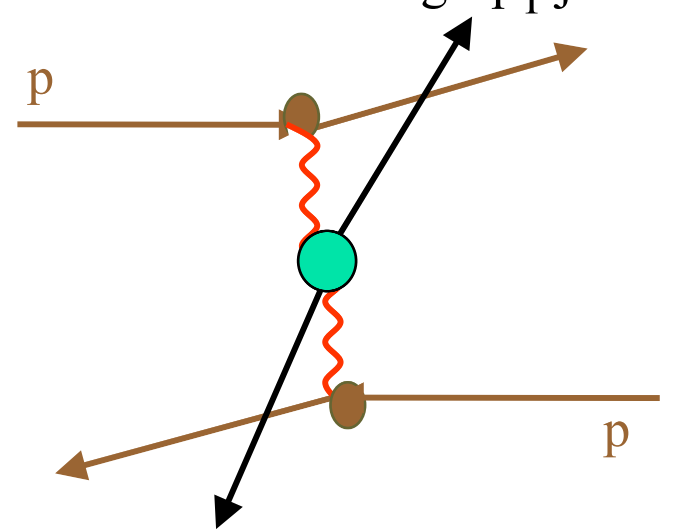


Single Diffraction

Large rapidity gap

1% of non-diffractive di-jets ×–section

- high-p_T di-jets, leptons
- charmonium (J/ψ), W, Z



Double Pomeron Exchange

(yet not directly observed)

Central *high* mass system

- high-p_T di-jets, leptons
- charmonium (J/ψ)

NB: Hard Diff. means: large p_T of jets, not large $|t|$

Why Hard Diffraction ?

it gives insight into the strong force

⇒ **Soft** ⇔ **Hard** regimes coexists

→ transition from perturbative to non–perturbative QCD

and unifications of the soft and hard aspects of the strong force

→ confinement and hadron structure

⇒ Pomeron Structure & Coupling

⇒ Diffractive Structure Functions

→ universality

→ Pomeron hadronic characteristics: gluon and quark content

⇒ factorization

UA8 ×–sect enhancement, exceeds factorization by 1 order of magnitude

⇒ large rapidity gap survival probability

⇒ topology final state: nature of Pomeron exchange

Why (Hard) Diffraction with STAR ?

high rates

→ need more experimental data (Tevatron still poor statistics)

→ observe directly 2 $\mathbb{P}$ exchange

W prodcution

→ compare pp to $p\bar{p}$

intermediate energy ($\sqrt{s}$ =200 – 500 GeV)

→ study transition from soft to hard diffraction

polarized beams offers a new window into diffraction

conclusive experiment still missing

hope it can be STAR

pA (not discussed today)

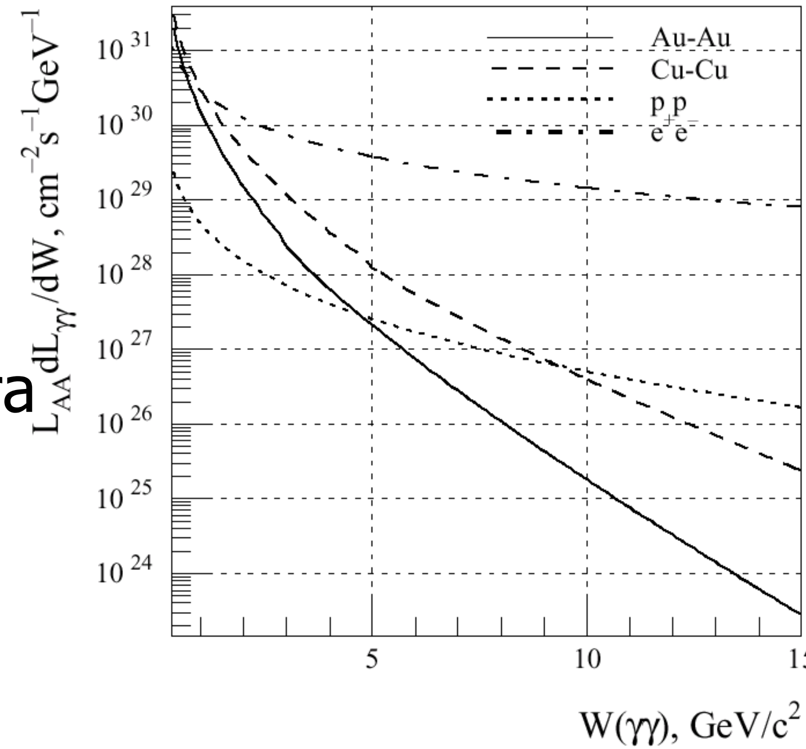
→ access the gluon distribution at small *x*

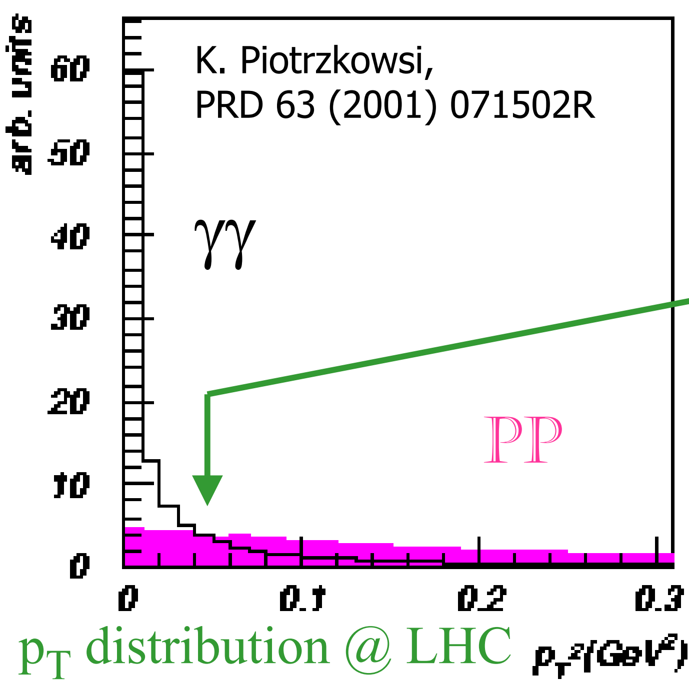
$\gamma\gamma$ with *pp*

- With 500 GeV pp,RHIC has higher $\gamma\gamma$ energy than LEP
- Rates are substantial
  - opportunity or background?
- $\gamma\gamma$ and $\mathbb{PP}$ have different p_T spectra

$\gamma\gamma$ Luminosity at RHIC

G. Baur et al, hep-ph/0112211





p_T distribution @ LHC

however

proton p_T^2 too small (< 0.05 GeV^2)

to select $\gamma\gamma$ with Roman pots

but can veto with Roman pots !

Next Steps

- develop further the Physics Case
- montecarlo studies of STAR acceptance
- beamline studies
- Roman pot setup and detectors
- form a group (STAR + new collaborators)
- proposal to STAR this fall